ELECTRONIC STRUCTURE OF CMR OXIDES

Fermi Surface Drives Fluctuating Nanoscale Phase Separation

Complex (or correlated-electron) materials are on the frontier of materials physics because conventional solid-state theory is often unable to explain their frequently novel behavior, high-temperature superconductivity being a prime example. Among these materials are the manganese oxide compounds that exhibit the colossal magnetoresistance (CMR) effect. An American-Japanese collaboration working at the Advanced Light Source has now shown that the quasiparticle concept, a pillar of current solid-state theory, does retain its validity in CMR oxides, but the peculiarities of the electronic structure result in rapid fluctuations at the nanometer length scale of separate conducting and insulating phases, fluctuations that appear to underlie the CMR effect.

CMR oxides undergo a transition from a paramagnetic insulator to a ferromagnetic "poor" metal as the temperature is lowered. Poor means the electrical resistivity is relatively high. An externally applied magnetic field can also drive this transition, which results in a "colossal" thousandfold decrease in the resistivity. The American-Japanese team studied the manganite compound $La_{1.2}Sr_{1.8}Mn_20_7$, whose crystal structure is built around double planes of manganese and oxygen atoms separated by lanthanum and strontium atoms. The CMR effect is thought to take place in these planes.

At ALS Beamline 10.0.1, the investigators were able to make angle-resolved photoemission spectroscopy (ARPES) measurements with much higher angular and energy resolution than before, which allowed them to conduct a comprehensive examination of the electronic structure of the material at low temperature in the conducting state. For example, they were able to resolve an energy band associated with the manganese-oxygen layers that exhibited the classic step-like drop in photoemission intensity as it crossed the Fermi energy above which electron quantum states are unoccupied, a telltale signature of quasiparticles with well-defined energies and momenta. They were also able to map the Fermi surface (contour in momentum space of the Fermi energy).

Here, the story becomes too complicated to tell in detail. In brief, calculation of the electrical resistivity from parameters extracted from the Fermi surface, the energy band, and other details of the photoemission spectra resulted in a value 10 times lower than measured experimentally. The shape of the Fermi surface, which has parallel straight lines, provided a clue why. Such lines are associated with electronic and structural instabilities (charge/orbital density waves cooperating with a Jahn-Teller distortion), for which there is evidence in $La_{1.2}Sr_{1.8}Mn_20_7$ from neutron and x-ray scattering experiments by other groups.

These instabilities give rise to a "pseudogap" (seen in the present, as well as past, ARPES measurements) in which the electron energy bands are pushed well below the Fermi energy and hence do not contribute to the conductivity. In the low-temperature conducting state, the pseudogap is not total, however, because there are nanometer-sized conducting regions with no pseudogap (where the quasiparticles are seen) as well as insulating regions with charge/orbital ordering. Moreover, competition between these regions causes fluctuations in their size and location with time. The net result is a poor metal at low temperature and an insulator at high temperature when the conducting regions disappear as the pseudogap grows stronger. ■

Dan S. Dessau (303-492-1607), Department of Physics, University of Colorado.

Y.-D. Chuang, A.D. Gromko, D.S. Dessau, T. Kimura, and Y. Tokura, "Fermi Surface Nesting and Nanoscale Fluctuating Charge/Orbital Ordering in Colossal Magnetoresistive Oxides," *Science* **292**, 1509 (2001).

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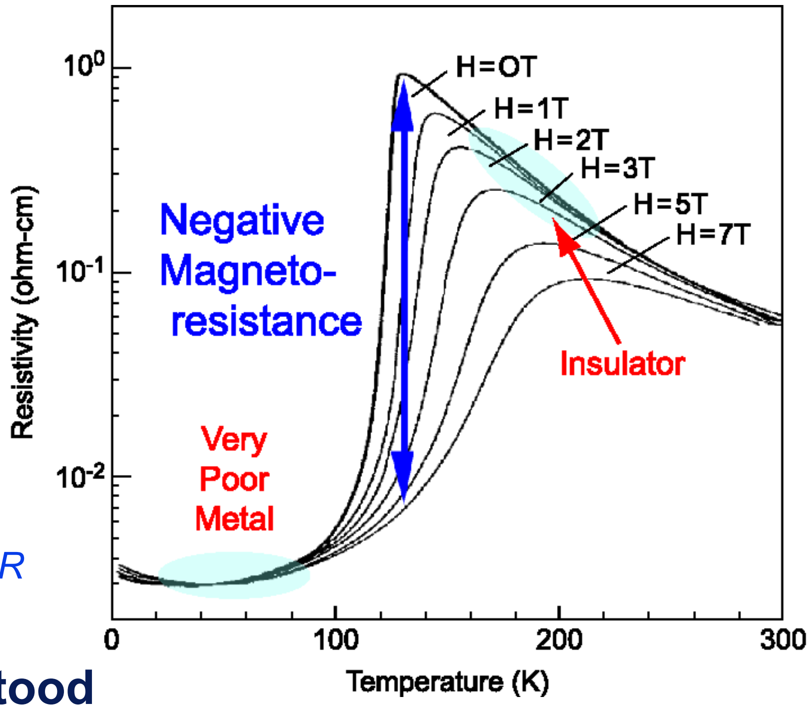
- **Complex (highly correlated) oxides at the frontier of solid-state science**
  - *Novel phenomena (high-temperature super-conductivity, colossal magnetoresistance, …)*
  - *Strong electron-electron correlations cannot be ignored*
  - *Quasiparticle model with well-defined electron band structure in doubt*
- **Colosal magnetoresistance (CMR) in manganese oxides**
  - *Resistivity decreased 1000 times or more in a magnetic field*
  - *Manganese-oxygen bilayers probable site of CMR effect*
- **Fundamental physics yet to be understood**
  - *Why is the metal conductivity so poor?*
  - *What causes the metal-insulator transition?*



Y.-D. Chuang (University of Colorado and ALS); A.D. Gromko and D.S. Dessau (University of Colorado); T. Kimura (University of Tokyo); and Y. Tokura (University of Tokyo and Joint Research Center for Atom Technology, Tsukuba). [*Science* **292**, 1509, (2001)]

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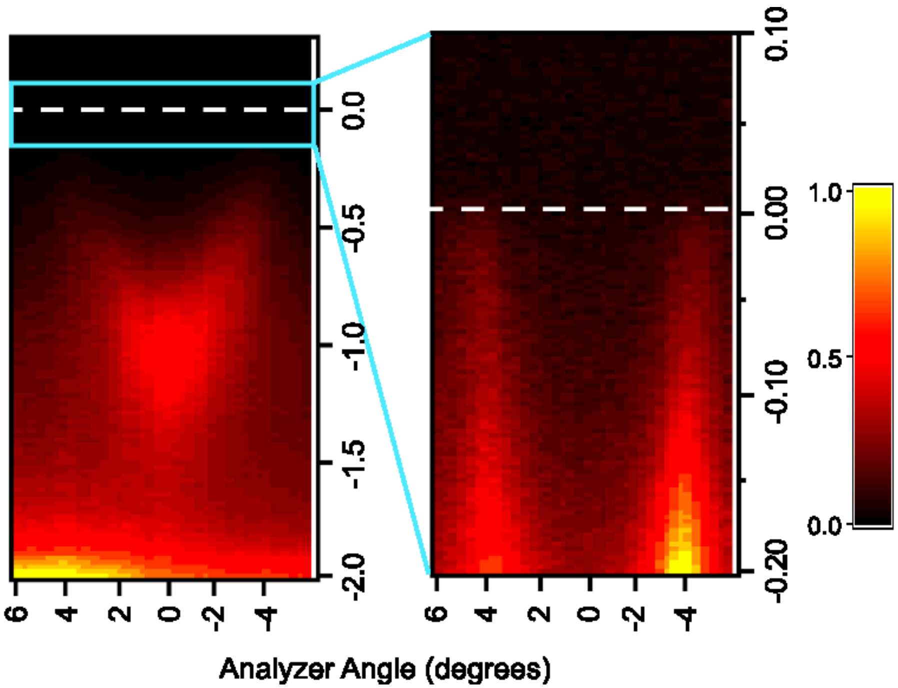
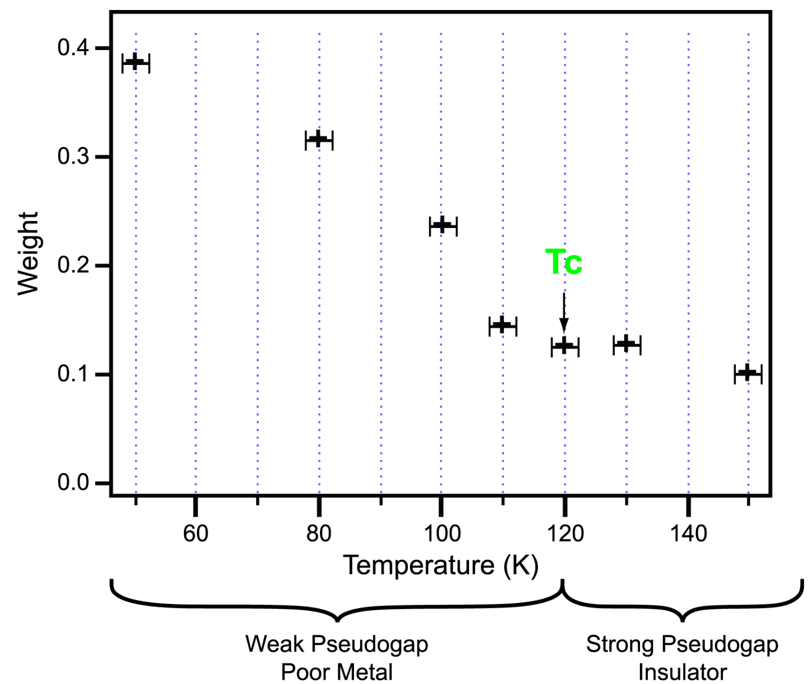
Fermi Surface Drives Fluctuating Nanoscale Phase Separation

- **Angle-resolved photoemission (ARPES) clarifies electronic structure**





LEFT – A quasielectron band extends to the Fermi surface in the low-temperature metallic state, but the low intensity (spectral weight) is indicative of a pseudogap that pushes most of the electrons to higher binding energies. RIGHT – The change in the spectral weight near the Fermi energy with temperature shows that the pseudogap grows stronger at higher temperatures, resulting in an insulating state.

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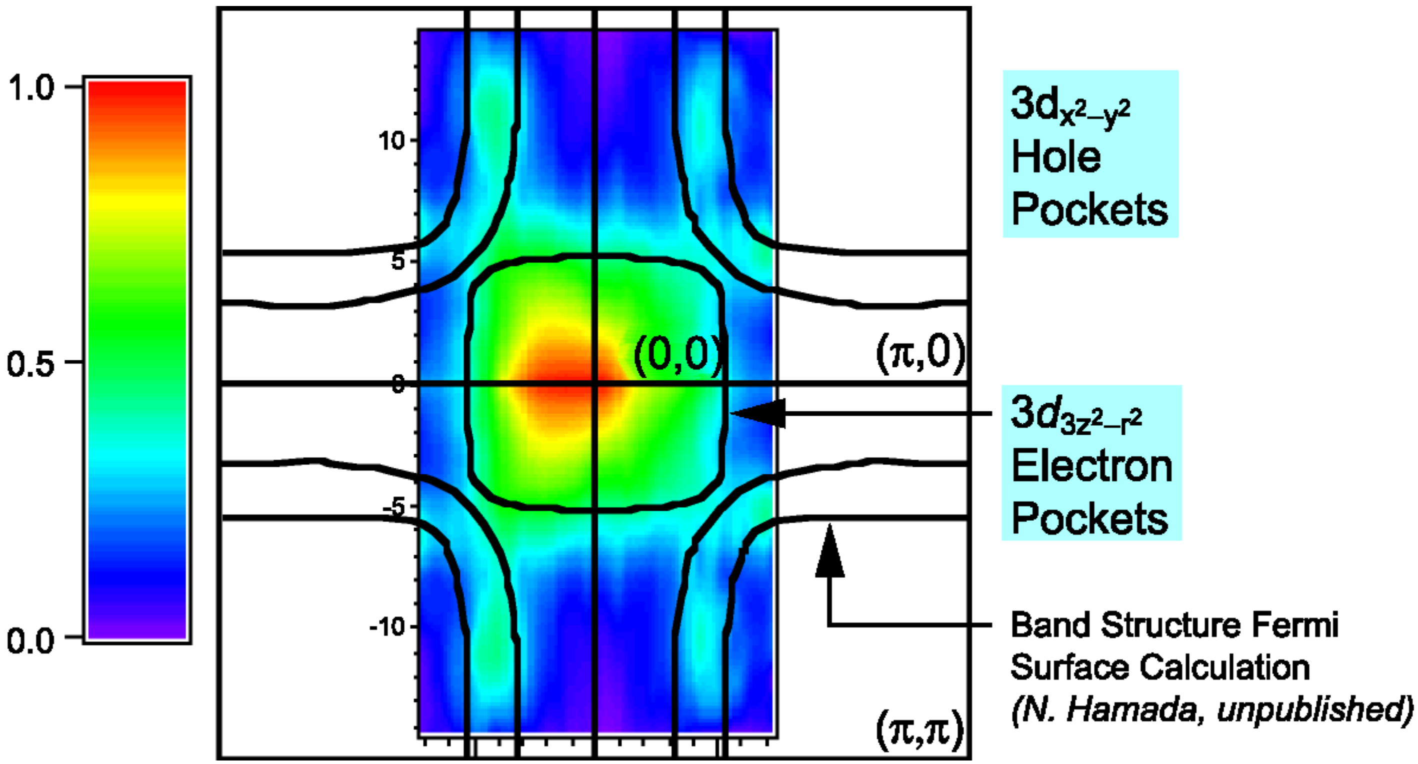

The long parallel sections of the experimentally measured Fermi surface, which well matches that calculated by theorists, are associated with instabilities that drive nanoscale fluctuating phase separation of conducting and insulating regions.

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